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Microsats for On-Orbit Support Missions

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It's great to be here today and I appreciate the opportunity to address this conference and describe some of our work and plans for future space missions and capabilities. My presentation will consist of a short overview of our program, some potential missions and enabling technologies, as well as, a description of some of our test vehicles and ongoing docking experiments. The Micro-Satellite Technology Program at Lawrence Livermore National Laboratory is developing technologies for a new generation of a very highly capable autonomous microsats. A microsat is defined here as a vehicle that's less than 100 kilograms in mass. We're looking at a number of different microsat design configurations, between 0.5 to 1 meter in length and less than 40 kg in mass.

You'll see several ground-test vehicles that we have been building that are modeled after potential future on-orbit systems. In order to have very aggressive missions, these microsats will require new integrated proximity operation sensors, advanced propulsion, avionics and guidance systems. Then to make this dream a reality a new approach to high fidelity "hardware-in-the-loop" ground testing, will be discussed that allows repeated tests with the same vehicle multiple times. This will enable you to "get it right" before going into space. I'll also show some examples of our preliminary docking work completed as of today.

A representative rescue microsat probe is shown that is less than a meter in length and less than 40 kilograms in mass with at least 300 meters-per-second of velocity change or delta-v. Depending upon the propulsion system and payload weight, up to 2 kilometers-per-second of delta-v is possible. It would be robustly outfitted with multiple sensors, both active and passive, along with the ability to recharge itself, find its attitude in space and update its inertial measurement unit with a star tracker. These are all elements of the basic features that you would need in order to carry out complex autonomous rescue missions. Our mission goals increase in complexity from simple rendezvous and inspection missions to more complex proximity-operations maneuvers that enable the vehicle to orient itself for eventual docking and servicing functions. Servicing functions in most cases require a redesign of the target vehicle itself so that it can accept robotic interfacing.

An inspection mission could consist of up close observations with a number of different sensors mounted on the vehicle. What's depicted in the simulation is a close-up inspection that is looking for micro-meteoroid damage, surface degradation from ultraviolet exposure, or vibration due to a wear and tear on gears and moving parts on the satellite. This collected data can then be stored and forwarded to the ground. As your missions evolve from just looking closely at another satellite, to flying closely around it and then to actually landing on a satellite, we believe you need both active and passive sensing capabilities. Some form of laser radar will be required in order to provide range and range rate in order to be able to land on the satellite. This particular microsat was designed as a possible rescue probe that was intended to land on the payload interface flange of a satellite and plug into its launch-vehicle-to-payload-umbilical connection. Once you're plugged in, you can trickle charge the batteries and basically reboot the computer, which is what was believed to have failed upon deployment. So this is a way to recover from this failure mode. You can think of this microsat as your road service in orbit or your "Triple A in the sky."

Another approach is to have the microsat carry a long tether that could be attached to a dead satellite. By deploying the tether, you can de-orbit the dead spacecraft much faster than what will occur naturally. For example, Irridium satellites will take about 100 years to de-orbit naturally from atmospheric drag; but with a tether, you could de-orbit these satellites in less than a year. From these examples, you see that in order to grapple something you will need some form of robotic arms and we are looking at ways that you could configure them. As your satellite constellations grow, another use for miniature spacecraft could be in managing your constellations, as a sort of high-tech "sheep dog in the sky," to help round up and watch your flock of satellites.

You also could design your satellites to provide a refueling capability. If you could annually refuel your satellites on-orbit at the rate at which you need propellant for orbital makeup, you could allocate more of the original payload to revenue generation. For example, let's say that a typical geo-stationary satellite uses about 100 kilograms of fuel a year, so that over a 15 year lifetime it will require approximately 1,500 kilograms of propellant. If you could guarantee that you could refuel this 100 kilograms every year, you could give your satellite an extra metric ton of up-front payload, whose revenue generating capability would more than pay for this annual refueling mission. These are some of the things that you can use with these microsat systems. Now, before you re-design your satellites to make them re-fuelable, you could choose to demonstrate this capability with the microsats themselves. If provided their own fuel depot in the sky, they could fly multiple sortie missions around different targets. If you deployed these fuel depots in various orbits, you then could fly your microsat from one orbit to the other, and greatly extend the functional capability of these small vehicles.

In the area of manned missions, clearly the International Space Station (ISS) could use these microsats as a way to help reduce some of the manned extra-vehicular activities or EVAs. These little robotics could inspect the ISS's solar rays for damage and could look for out-gassing from the station's modules due to micrometeoroid impacts. These microsats could be used daily as a normal robotic inspection probe that could minimize some of the EVA mission load.

As technology continues advancing, performance improvements can be expected, and the sky is not the limit here. In addition to microsats, there's technology on the way that will allow us to have nanosats (defined as less than 10 kilograms in mass) and picosats, which are on the order of only one kilogram. You could plan to pre-deploy these nanosats and picosats with your main satellite, and use them to watch the on-orbit deployment of your main satellite. By observing the shroud ejection and subsequent satellite deployment, you could use this record of the event in case of an accident, to determine what happened and who may be at fault. Was it the launch vehicle provider or was it the satellite manufacturer that caused the problem and who should be compensated for a non-functioning satellite. These nanosats and picosats will be small enough to be carried on the microsats themselves. This will enable them to provide a type of "plug and play" feature to a larger satellite. The nanosat/picosat could potentially be an upgrade to your larger satellite to enhance its performance. For example, if you wanted a processor upgrade, let's say, a future "Pentium 10," you could use the microsat/nanosat combination to plug this processor upgrade into your satellite while its on-orbit. Extending its capability and useful lifetime.

Some of the enabling technologies include state-of-the-art sensing, both miniature cameras and miniature radars (or laser radars), and advanced software/avionics that are becoming available in the commercial sector. Where you can't get things commercially, you have to build your own, especially in the area of advanced propulsion systems. Vehicle propulsion provides the agility and maneuverability needed for all of these missions. We have been using non-toxic propellants that offers a safe manned environment for vehicle testing. We have also developed a way to test these vehicles on an air-table, which provides a high fidelity hardware-in-the-loop test capability. Here are some examples of the kind of vehicles that have been tested over the last few years. The first two, upper left and lower right, are cold-gas vehicles, the other two diagonal vehicles are liquid propellant ones and have all been successfully operated multiple times.

The engineering test vehicle ETV-250, (shown in the lower right hand corner of the four-vehicle chart) is our latest docking test vehicle. Earlier I mentioned that we had developed an approach to allow us the ability to test fly these vehicles with high fidelity on the ground before going into space. What we developed is a test apparatus that holds the vehicle at its center-of-mass using a floating spherical air bearing that provides the vehicle with three "angular" degrees-of-freedom. This spherical bearing itself floats on another two "translational" degrees-of-freedom tripod that also floats on an air-table. With this the microsat can fly itself along the table and carry out most of the missions it could do in orbit. It is able to use nearly the same software, and doesn't have any extra mass attached to effect the attitude control of the vehicle. This enables you to repeatedly operate our microsat test vehicles and run our experiments over and over again, until we perfect their functionality. In fact, as the robotic tasking becomes more complex, you will need to run these experiments again and again until you get it right. We also find that the real world is so complex that there are unforeseen interactions between hardware, software and the environment, that requires a thorough exploration of the full range of non-deterministic behaviors of these vehicle systems. To do this requires working with the actual hardware and not just a software simulation. This ground test approach allows us to risk mitigate to a point where you can really believe that your vehicle can go up and successfully do the experiment. This is important so that the rescue vehicle itself doesn't need to be rescued.

For our docking experiment, we developed a small vehicle with a grappler on its nose to allow us to demonstrate a fully autonomous soft docking capability. The plan was to go after an older test vehicle that would carry a target ball for the grappler to grab. In addition to the grappler, we included a mega-pixel tracking-camera, a laser ranger, and a pair of color cameras for stereo imaging and a telepresence capability. The table is approximately seven meters long and the two vehicles are located at opposite ends of the table. The vehicle in the foreground (at the bottom left) held itself onto a target ball (at the right in the photograph) and then released itself and acquired the target at the other end of the table. It then began to move forward, using stereo ranging. It stopped about two meters out and flew sideways to orient itself directly normal to the vehicle's target board. It then started using the laser ranger to maneuver itself all of the way in, close enough for the grappler to grab the ball. One image shows the vehicle about to grab the target ball and once it grappled the ball, we were able to demonstrate towing, both pulling and pushing of the target vehicle.

In summary, we believe that it's possible to go after a variety of advanced mission capabilities with this new class of microsat rescue vehicles. These missions include inspections, proximity operations, docking and servicing functions such as repair and re-fueling. To do these future missions requires the development of new advanced integrated sensing, propulsion, avionics and software systems. You will also need a high fidelity ground test capability that allows you to practice these missions and vehicle functions repeatedly until you can reliably perform them on the ground. With this capability robustly demonstrated on the ground, you then can expect to successfully carry out these complex missions on-orbit. In the future, we envision that these capabilities will become commonplace and will be routinely used as we now use the current generation of communication and remote sensing satellites.

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